Integration of Surface Regolith Mapping and Soil Field Measurements with Geochemistry in a Till-Covered Terrain, Lara Volcanogenic Massive-Sulphide Deposit, Southern Vancouver Island (NTS 092B/13)

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Introduction

A technical challenge faced by mineral exploration is the detection of mineral deposits buried under younger exotic geological units. Conventional surface-media geochemical methods using strong acid digestion examines endogenic mineral particles. Sample types such as soil, stream sediment and till are capable of detecting a primary metal signal that has been eroded and dispersed from a bedrock source (McClenaghan and Cabri, 2011); however, this method may not be appropriate if mineralization is buried by thick or complex cover (Eppinger et al., 2013).

Advances in analytical equipment have made accessible relatively rapid and affordable multi-element analyses with reduced lower detection limits. Using weak acid digestions and selective extractions, subtle geochemical signatures have been shown as accumulations of labile ions thought to be weakly bonded to components in the soil (Cameron et al., 2004; Kelley et al., 2006; Hamilton, 2007; Aspandiar et al., 2008; van Geffen et al., 2012). The authors propose that the labile ions migrate vertically from an oxidizing sulphide body by a combination of mechanisms including electrochemical transport, diffusion and gaseous or biological activity, eventually accumulating near the surface (Figure 1; Aspandiar et al., 2008; Anand et al., 2016). While anomalous responses have been observed above buried mineral deposits, there remains a fundamental lack of understanding of the processes that control ion dispersion. Identification of these processes will improve survey design and analyses and interpretation of geochemical datasets, including the recognition of misleading or false positive signatures and situations where false negatives may arise.

The total concentration of a trace element at surface is a function of many factors that promote or inhibit ion mobility. These factors include overburden chemistry (redox state, pH) and texture, surface vegetation, topography and hydrology. As part of the Exploration Geochemistry Initiative at the Mineral Deposit Research Unit (MDRU) at the University of British Columbia (UBC), ongoing research will map major-, minor- and trace-element distribution at the surface above a massive-sulphide target to identify the processes and controls on labile ion mobility. This research is a study of processes with widely applicable results. This paper will describe surface regolith mapping and soil sampling fieldwork completed in May–September 2015.

Background

Research is centred on the Lara volcanogenic massive-sulphide (VMS) deposit in the Cowichan Valley Regional District of southern Vancouver Island (NTS 092B/13; Figure 2). The landscape is characterized by moderately rugged mountains (1000–1200 m) flanking the Sully creek valley (600 m). The area is covered by an approximately 70 year old mature second-growth forest with a 125 m wide clearing down the axis of the valley for a high-voltage electric power transmission line.

The Lara VMS deposit was selected for this study on the basis of satisfying three criteria: sulphide mineralization in bedrock; widespread, relatively uniform surface cover; and minimal anthropogenic surface disturbance. Available geographic and drillhole data was consulted in order to select the optimal sampling area with proven mineralization and the least surface disturbance.

Bedrock Geology

The Lara deposit (MINFILE 092B 129: BC Geological Survey, 2015) is an unmined Zn-Cu-Pb resource hosted in the mid-Paleozoic Sicker Group volcanic rocks of the Wrangell terrane (Massey, 1995a, b; Yorath et al., 1999). The rocks underlying the study area comprise intermediate to felsic volcanic and fine-grained tuffaceous volcani-

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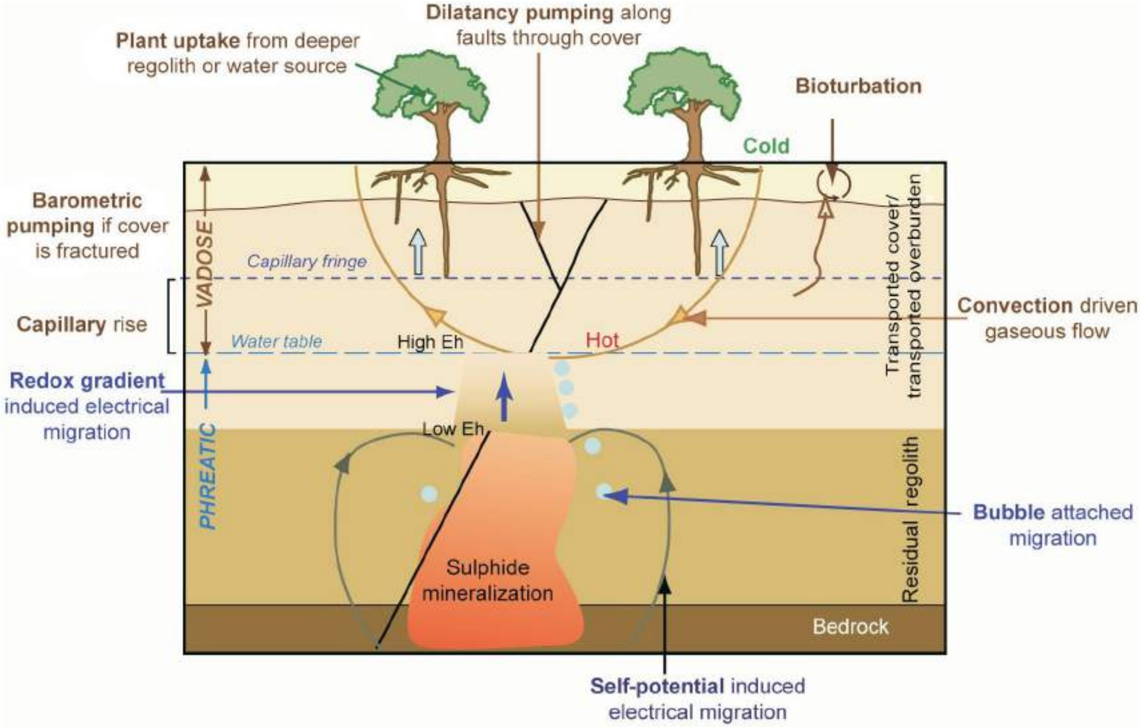

Figure 1. Schematic of proposed mechanisms of element migration in a buried mineralization setting (Aspandiar et al., 2008).

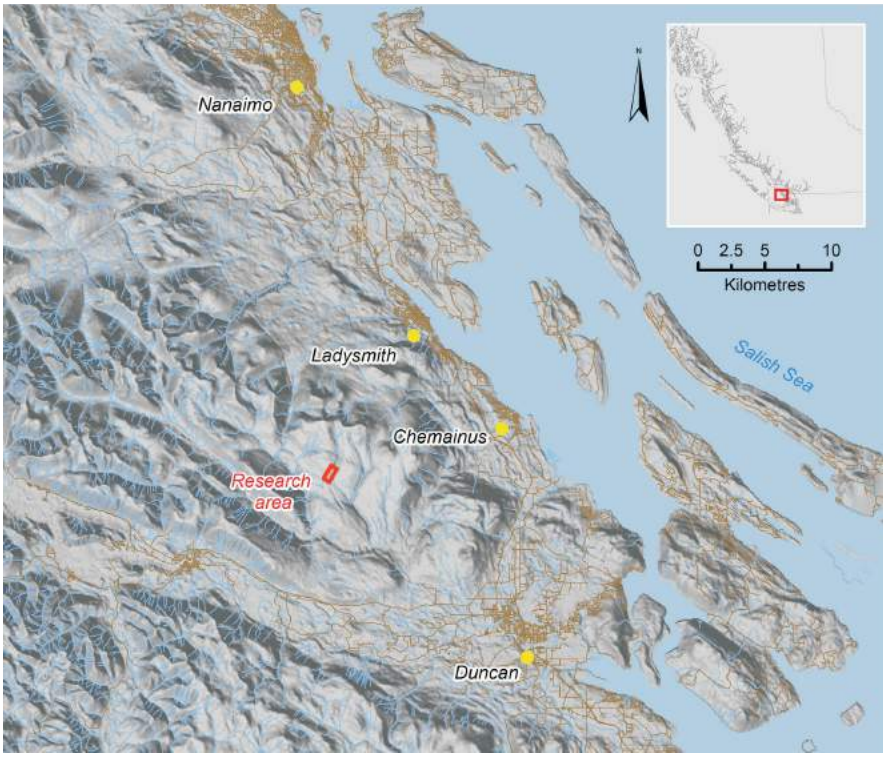

Figure 2. Location of the research area (outlined in red).

clastic rocks of the McLaughlin Ridge Formation intruded by late Triassic dikes and sills of the Mount Hall gabbro (Figure 3; Massey, 1995a, b). Mineralization is hosted within the McLaughlin Ridge Formation, which also hosts numerous other VMS showings along strike. The current indicated resource of approximately 1.2 Mt at 3% Zn, 1% Cu, 0.6% Pb, 33 g/t Ag and 2 g/t Au at a 1% Zn cut-off is hosted by strongly silicified, coarse-grained rhyolite crystal tuff and ash tuff (Kelso et al., 2007). Mineralization comprises banded and laminated accumulations of sulphide minerals up to 16 m thick with occasional sulphide stringers and breccia with a sulphide matrix. Disseminated sulphide minerals are also noted in hostrocks. Historical trenching along strike from the study area identified a massive-sulphide lens with 25 g/t Au, 500 g/t Ag, 3% Cu, 43% Zn and 8% Pb over 3.5 m. (Kelso et al., 2007). Mapping by Ruks et al. (2008) further described the local mineralization as dark grey to black, medium-grained massive sulphides dominated by black sphalerite with lesser chalcopyrite and pyrite with scattered 2 cm by 10 cm carbonate blebs hosted by intensely silica-sericite–altered felsic ash tuff.

Surficial Geology

The Quaternary sediments of southern Vancouver Island record a dynamic glacial history. Up to three glacial advances and interglacial periods have deposited and locally reworked sediments across the region (Mathews et al., 1970; Armstrong and Clague, 1977; Alley, 1979; Alley and Chatwin, 1979; Clague et al., 1980). The surficial materials in the study area potentially range in age from >125 000 to 15 000 years BP but most were likely deposited during the Vashon stage of the Fraser Glaciation (25 000–15 000 years BP; van Vliet et al., 1987; Easterbrook, 1992). The area is considered to have been free of ice by about 13 000 years BP (Alley and Chatwin, 1979). The study area is characterized by a blanket of basal till in the valley base; till mixed with colluvium is interpreted to dominate the upslope regions (Blyth and Rutter, 1993). Overburden cover is between 2 and 15 m thick based on drill records (Kapusta et al., 1987).

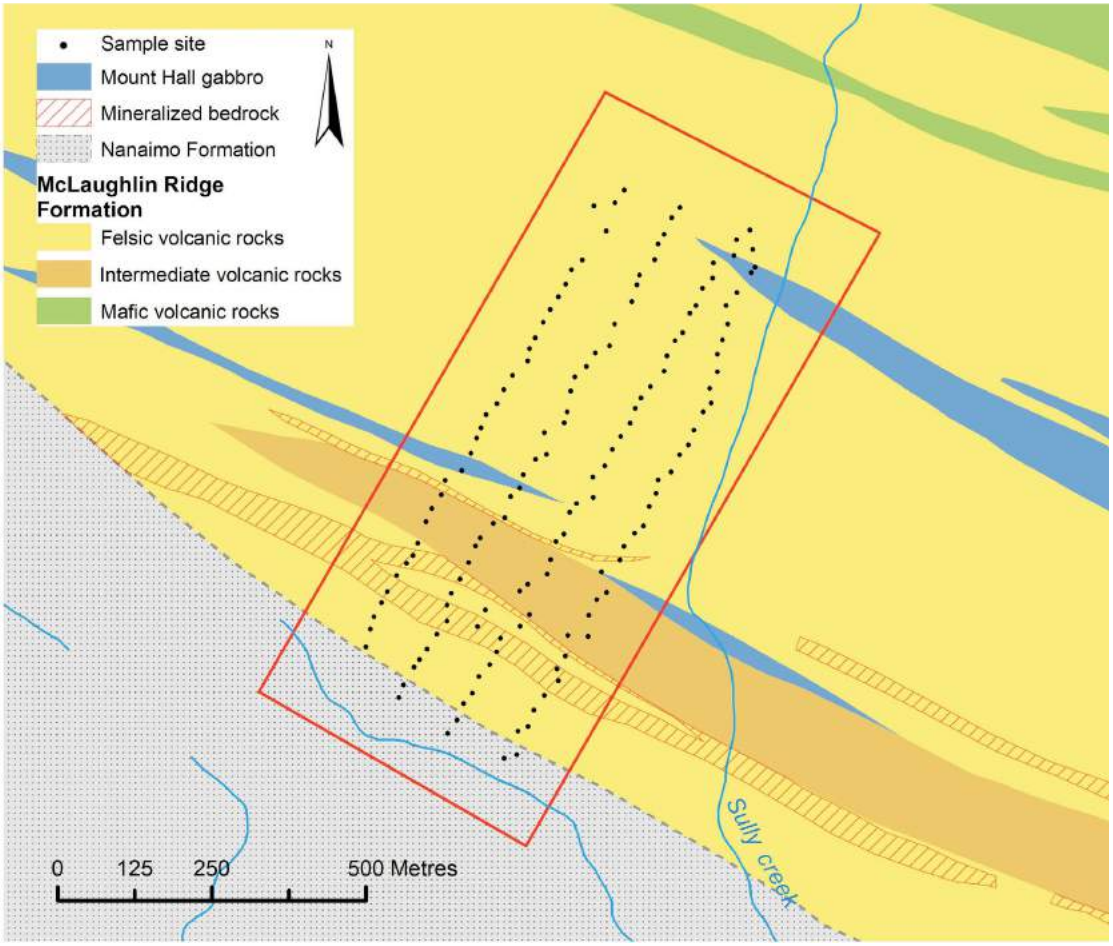

Figure 3. Geology of the study area with interpreted surface projection of mineralized bedrock (after Wetherup, 2010). Soil sample locations are shown as dots. Place names with the generic in lower case are unofficial.

Research Project

Fieldwork was undertaken to support the following research objectives:

- identify the processes and controls on labile ion mobility
- identify processes contributing to false positive or false negative signatures
- develop a process-based model of trace-element dispersion in the near-surface environment above massive-sulphide mineralization

The following work was completed to characterize the composition and variability in the surface environment and characterize the chemistry and physical properties of the shallow soil.

Surface Mapping

Comprehensive surface mapping was completed prior to the soil sampling program. An area of approximately 0.6 km^2 was included in this exercise, with a 100 m buffer beyond the proposed limits of sampling. Airphoto and geographic data from the TRIM database were used for preliminary mapping and fieldwork strategy, with a total of five days of field data collection.

A series of traverses were completed along the boundary of the study area and proposed sampling lines to map glacial sediments, geomorphology, dominant vegetation and anthropogenic disturbances. Mapping was done directly into mobile GIS software with integrated global navigation satellite system (GNSS) positioning. A total of 48 surface pits and roadcut sections were compiled to generate a map of major surficial domains that were used to modify soil sampling locations as appropriate. The mapped units were further refined following sampling, adding a further 150 control points.

The area is densely vegetated by Douglas fir with lesser western hemlock and western red cedar tree cover. Fern, salal and Oregon grape bushes cover much of the exposed forest floor. Rare 20 by 50 m stands of cedar provide a distinctive surface environment of relatively little sunlight exposure, loose litter or floor vegetation. Alder is the sole broadleaf tree growing in recent clearings or large drainages where sunlight and moisture are readily available.

Four domains of surficial material are observed in the study area (Figure 4): the original till blanket making up the residual surface, erosional gullies and depositional materials (fluvial and alluvial deposits). All materials have been modified by anthropogenic activity.

Till

The prevailing material at the surface is a basal till blanket. This unit is relatively unmodified from original deposition except for localized overturn by fallen trees. The till is poorly sorted with mixed clasts of variable grain size and angularity. Locally derived felsic volcanic clasts are generally angular due to their schistose fabric and rarely exceed 10 cm in diameter. The remaining clasts are a mixture of subangular to rounded granodiorite, gabbro and siltstone up to 30 cm in diameter. Although most locations indicate a massive till blanket, one roadcut section revealed a 30 cm bed of coarse sand between till blankets, suggesting intermittent local fluvial activity (Figure 5). A bed of well-sorted coarse sand between till blankets may alter the local hydraulic regime.

Erosional Gullies

Erosional gullies are generally steep (~45°) with patchy salal bush cover and exposed soil. Profiles within the erosional slope reveal a mixture of oxidized B horizon with patches of less oxidized relict C horizon, suggesting reworking with downslope movement. This latter till appears to bury antecedent masses of roots. Soil sampling was avoided in drainage gullies due to the recent reworked surface materials.

Fluvial Deposits

Fluvial deposits were observed in the active Sully creek channel and in a smaller stream that crosses the southwestern corner of the map area. These deposits are composed of boulders, cobbles, pebbles and sand deposited in a braided channel. This unit is considered to represent the coarse lag of till slumping into the creek channel where clay and silt are carried downstream. Bedrock exposures were observed in the Sully creek gully basin. Sampling this unit was avoided due to the recent reworked surface materials.

Alluvial Deposits

Alluvial deposits was the most difficult unit to recognize in the field. Located near the base of hill slopes where slope angle decreases, alluvial sand and gravel appeared to be a result of seasonal water flow as a network of channels across the forest floor (Figure 6). These networks begin at the terminus of erosional gullies representing the redeposition of material from the erosional gully slope. Samples were not collected in obvious corridors of water flow and deposition.

Anthropogenic Clearings

Anthropogenic activity was evident across the research site as decomposing tree stumps from logging old-growth forest are common. Clearings younger than the second-growth forest could be identified by alder and thick fern with a lack of coniferous forest. Road berms and clearings from previous logging activities and more recent exploratory drilling were mapped in detail to guide sample placement. Most drillhole locations are clearly marked with a labelled sign and casing removed.

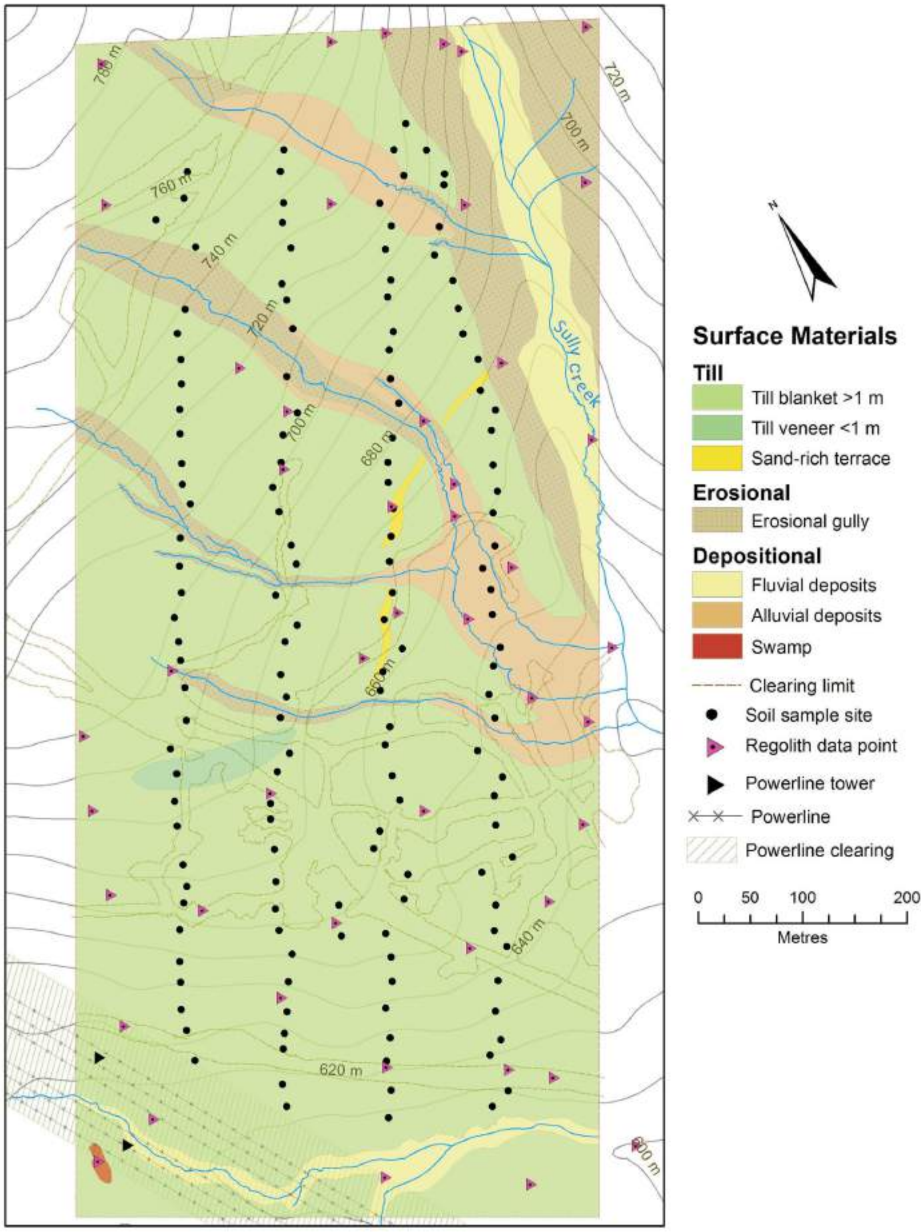

Figure 4. Preliminary map of surficial materials in the research area. Place names with the generic in lower case are unofficial.

Soil Profiles

Soil profiles are well developed with notable variability in horizon thicknesses. Many sites show an excellent O-Ah-Ae-B-C progression (Figure 7a, b); however, complex profiles were occasionally noted (Figure 7c, d). Development of a grey-white powdery Ae horizon appeared to preferentially form around larger root systems and follow along the surface of boulders 2–8 cm below the general base of the Ae horizon.

Sampling and Field Measurements

The sampling grid included four lines, 100 m apart, and was approximately 1 km long with soil samples collected at 25 m intervals. The grid was designed to cut mineralization perpendicular to strike and cover the hostrocks. By crosscutting different hostrock types (mafic to felsic), additional insights into the formation of false anomalies may be identified. At each sample site a suite of in situ and slurry-based physical properties were measured. The first measurements taken were electrical conductivity (EC), soil moisture and pH of the undisturbed pit wall in each of the soil horizons (Figure 8a).

Samples were then collected from the upper B horizon at the pit wall. The B-horizon soil was chosen because it is consistently present and suited to routine sample collection. Using clean nitrile gloves and a nylon trowel, soil was

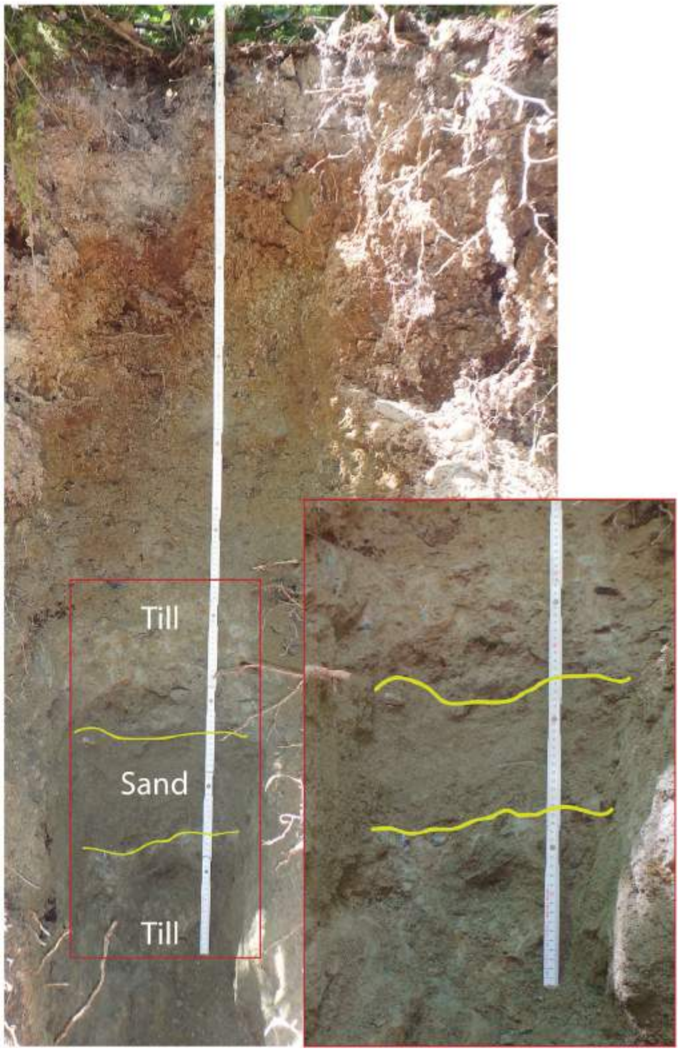

Figure 5. Roadcut section showing a 30 cm bed of well-sorted, coarse sand between till. Total pit depth is 160 cm; the top of the sand layer is 120 cm from the top of the pit. Note the extended weathering profile, including a mottled transitional zone between B and C horizons.

Figure 6. Typical shallow-angle gravel depositional channel.

removed from between 3 and 13 cm below the base of the Ae horizon. The soil was sieved to –6.3 mm using a stainless steel screen until approximately 1.5 kg was collected. A small air-tight zip polythene bag of sieved material (~500 g) was collected for hydrocarbon analysis and a second was collected for microbial analysis (Figure 8b). A further 60 ml was taken for slurry-based measurements and the remainder packaged for chemical analysis in a polythene bag sealed by zip tie. Oxidation-reduction potential (ORP), pH, pH following acidification, total dissolved solids (TDS) and free chlorine measurements were taken on 1:1 de-ionized water:soil slurries (Figure 8c).

Samples were submitted to ALS Minerals (North Vancouver, BC) for drying at <60°C, screening to –180 µm followed by multi-element inductively coupled plasma–mass spectrometry (ICP-MS) analysis with aqua-regia digestion and again with de-ionized water extraction. A split of the original sample and the screened fraction was retained for further research. Total organic carbon of the 180 µm fraction was measured by combustion furnace and infrared spectrometry at ALS Minerals. Samples for hydrocarbon and microbial analysis have been retained by the authors for further research.

Soil Hydrocarbon Measurements

A passive hydrocarbon collection module was deployed at each sample location. The module is composed of activated carbon wrapped in waterproof but vapour-permeable expanded polytetrafluoroethylene (ePTFE) tubing (Anderson, 2006). A narrow punch was used to penetrate the soil at the base of the sample pit. The modules were inserted in a vertical orientation and covered with soil. After 60 days, the modules were recovered, placed in air-tight glass vials and submitted for analysis of up to C_{20} hydrocarbons at Amplified Geochemical Imaging (Newark, Delaware, United States).

Self-Potential Survey

Self-potential describes naturally occurring electrical fields at the Earth's surface, useful for identifying bodies of sulphide mineralization at depth. A 4175 m line survey was conducted over the research area using a pair of nonpolarizing Cu-$CuSO_4$ porous ceramic electrodes, 1000 m of 12-gauge cable and a high-impedance voltmeter. A base electrode was installed at the north corner of the site and a second roving electrode was moved to each sample location downslope. Normal- and reverse-polarity resistance and DC voltage measurements were recorded. Each sampling line was surveyed separately followed by tie lines at the top and bottom of the survey. Due to a high-voltage electrical

Figure 7. Variability in soil profile development: **a)** a typical idealized profile; **b)** a similar profile with less organic surface litter; **c)** a poorly developed soil profile; **d)** the rare occurrence of duplicated horizons.

Figure 8. Sampling procedure: **a)** the direct soil measurement of electrical conductivity; **b)** a completed sample with the pit showing a portion of the B horizon removed; **c)** slurry-based measurements in the field, including free chlorine on the left and pH on the right.

transmission line at the southern end of the grid, additional processing is required to reduce or eliminate noise.

Conclusions and Future Work

Mapping the surficial materials present in the research area prior to sampling was valuable in eliminating inappropriate areas of younger reworked material. Future work will integrate the field observations and measurements with analytical results to evaluate the chemical variability of the surface environment unrelated to the presence of mineralization and, hence, clarify the anomalous response above mineralization. Additional sampling of selected sites for vegetation and other horizons will be undertaken to clarify potential anomaly formation mechanisms. The research will be completed in August 2016.

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